

# Load Resistor as a Worst-Case Parameter to Investigate Single-Event Transients in Analog Electronic Devices

I. López-Calle, F. J. Franco and J. A. Agapito

Departamento de Física Aplicada III – Facultad de Físicas  
Universidad Complutense de Madrid  
Madrid (SPAIN)  
isabelcalle, monti, agapito @fis.ucm.es

J. G. Izquierdo

CAI de Espectroscopía, Facultad de Químicas  
Universidad Complutense de Madrid  
Madrid (SPAIN)  
jgonzal@quim.ucm.es

**Abstract—** One of the main phenomena that commit the reliability of analog electronic systems working in the outer space is the presence of energetic ions that produce spurious transients after crossing the device. These pulses are transmitted to the network loading the device and can eventually lead to dangerous situations as it has been observed in some spatial missions. This paper shows how the value of the resistor loading the device can affect the shape of the transients.

**Keywords-** Analog devices, bipolar technology, laser tests, single event transients, system reliability, two-photon absorption.

## I. INTRODUCTION

Single Event Transients (SETs) are phenomena that occur in analog electronic devices after the pass of a flying charged particle [1]. The origin of this particle is usually associated with cosmic rays (E.g., military or aerospace applications), nuclear facilities, radioactive impurities (Thorium or uranium inside the silicon bulk), etc. If the particle goes through an integrated charged capacitor (typically, a reverse-biased PN junction), it is created a cloud of free charged carriers along the path of this ionizing particle. This plasma of free particles is drained by the electric field behaving like a current pulse that induces a short transient that eventually manages to reach the device output leading to a temporary anomalous output value.

A lot of factors affect the shape of these transients: The kind and energy of the ion, the sort of technology, the feedback network, the input values, etc [2-11]. Load effects have been studied in several structures although attention is usually paid on capacitive loads putting aside other kinds such as load or pull-up resistors.

## II. TEST SET-UP

Two typical analog devices (The LM124, an operational amplifier, and the LM311, a voltage comparator with pull-up resistor) were decapsulated and placed in typical bias networks (Fig. 1). Both devices are built in bipolar technology and their behaviors during the single event tests have been deeply studied in the literature. Every device was illuminated with an 80-fs pulsed laser the wavelength of which was 1300 nm, a technique called “Two Photon Absorption” to induce SETs that

avoids the drawbacks of using an ion beam. These transients were recorded by a digital oscilloscope and stored by a personal computer for a later analysis. Several SETs depicted in the literature were checked changing the values of the load resistors to investigate the effects of this parameter on them.

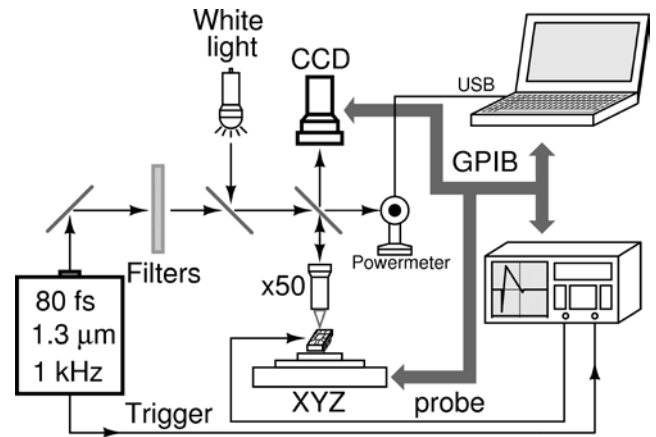


Fig. 1: Schematic of the experiment set-up

## III. RESULTS

### A. Operational Amplifier

A popular operational amplifier, the LM124, was biased as a voltage follower loaded with a resistor connected to ground. This amplifier is manufactured by National Semiconductors [12] and can be found in many applications of electronics boarded in spacecrafts.

Typical transients are caused when an ion hits one of some specific transistors of the device: Transistors in the input differential pair, inside the gain stage, current mirrors, etc. Very interesting effects related to the load resistor value were observed in two of the most sensitive transistors: Q09 and R1, both in the gain stage, the meaning of which can be found in the manufacturer's datasheet. Q09 is a transistor in a typical CC-CE configuration and its related transients are negative peaks that can even reach the negative saturation voltage. They

are usually very long since the recovery is controlled by the slew rate value ( $\sim 0.3\text{-}0.5\text{ V}/\mu\text{s}$ ). R1 is actually an open-base NPN transistor working as a resistor to drain the excess of current from the Q09 base [10]. Transients are usually sharp positive peaks followed by a negative peak the recovery of which is controlled by the slew rate value.

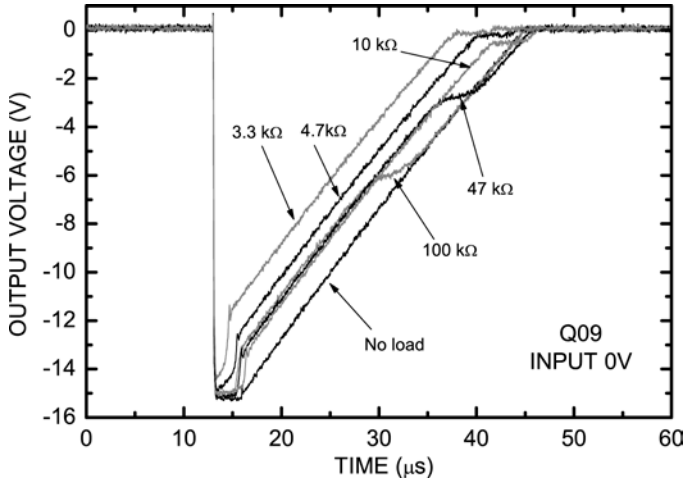


Fig. 2: Single event transients induced at Q09, an NPN transistor in the gain stage of the LM124. The size and the duration of the transients decrease as the load resistor value does.

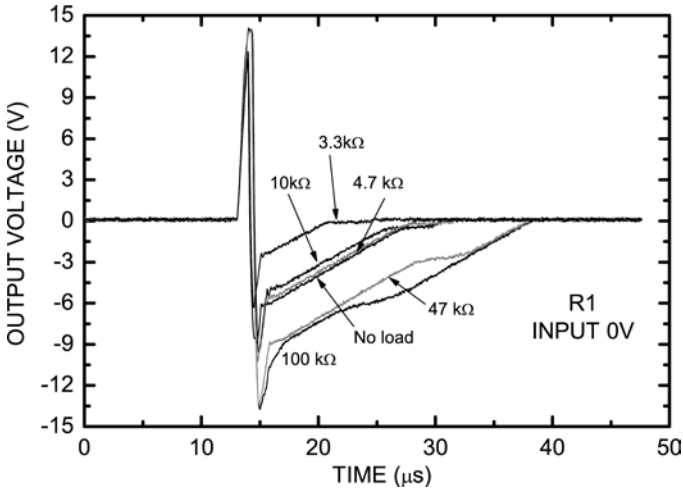


Fig. 3: Single event transients at QR1, an NPN transistor with open base acting as a resistor to drain the excess of base current at Q09. In this case, the load resistor accentuates the second stage of the transient.

In general, load resistors below  $10\text{ k}\Omega$  mitigate the SETs reducing the duration of the transients (Fig. 2 & 3). Indeed, if the value of the load resistor is low enough, some of the output transients do not occur (E. g., some transients induced in the buried layer beneath R1). However, this is not a monotonous trend since, in several situations, intermediate values of this parameter can worsen the transients due to the appearance of strange plateaus that make the transients longer. Thus, Fig. 3 shows the transients related to R1 where those related to the  $47\text{ k}\Omega$  &  $100\text{ k}\Omega$  resistors are longer than the rest of transients. The reason of these transients being so different is just the

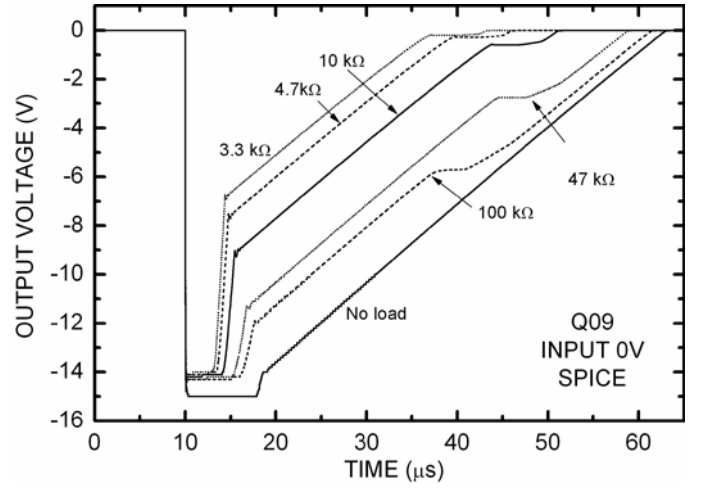


Fig. 4: SPICE simulation of the single event transient in Q09. This graph is equivalent to Fig. 2.

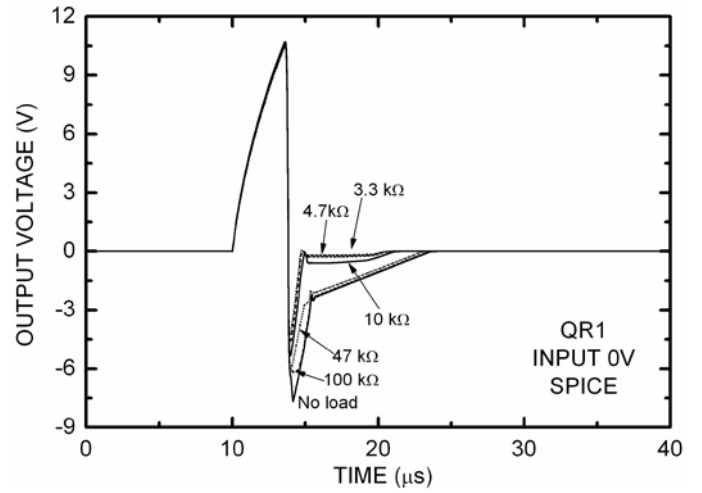


Fig. 5: SPICE simulation of the single event transient in QR1. This graph is equivalent to Fig. 3.

anomalous behavior of one of the transistors of the over-current protection block that works in reverse-biased zone instead of the typical cut state.

An equivalent behavior was observed in SPICE simulations of the SETs following the typical recommendations [13]. The SPICE micromodel was created from a source found in the literature [10] with typical transistor parameters [14]. Despite the differences due to the micromodel approximations, Figs. 4 & 5 are similar to the actual behavior of the operational amplifier.

### B. Voltage Comparator

In this case, the tests were performed on a typical open-collector voltage comparator, the LM311, loaded by a pull-up resistor [15]. The adequate selection of the pull-up resistor can change the size and shape of the SETs. In this device, there are only two kinds of transients: Positive-going and negative-going depending on the initial logic output value (LOW or HIGH).

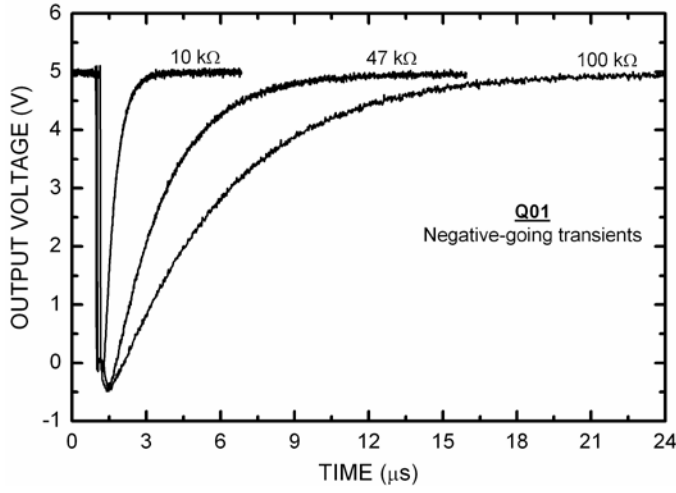


Fig. 6: Negative-going transients measured in the LM311 voltage comparator. Logic output levels are TTL-compatible.

Both transients were induced hitting each transistor of the input differential pair with the laser (Q01 & Q02 according to the manufacturer's datasheet). The influence of the pull-up resistor value is pretty clear: Thus, negative-going SETs become longer and longer as the pull-up resistor value increases in such a way that an incorrect choice of this resistor can increase the duration of the SET in two orders of magnitude (Fig. 6). On the contrary, positive-going transient duration grows as the pull-up resistor value decreases. Indeed, they can even disappear whilst the opposite transient are the longest (Fig. 7).

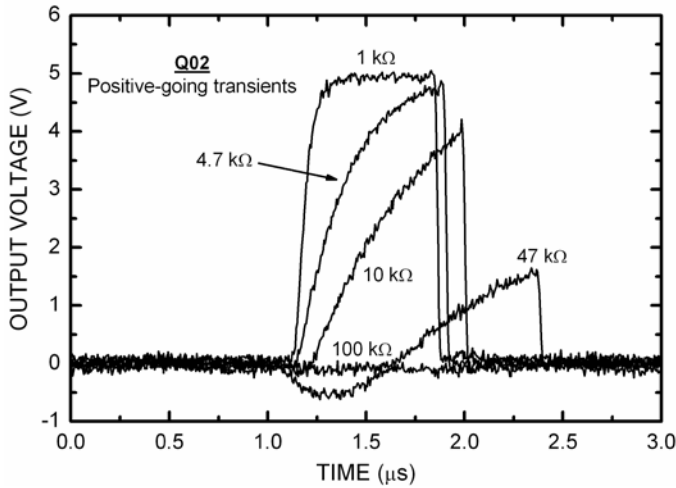


Fig. 7: Positive-going transients measured in the LM311 voltage comparator.

All of these experimental phenomena were simulated by a SPICE micro-model in order to account for the truth of the experimental results (Figs. 8 & 9). Like the operational amplifier, the simplifications of the micromodel make the simulated transients a bit different than the actual ones: E. g., all of the positive-going simulated transients last for more or less the same time whereas there are clear differences of duration among the actual transients as the pull-up resistor value increases.

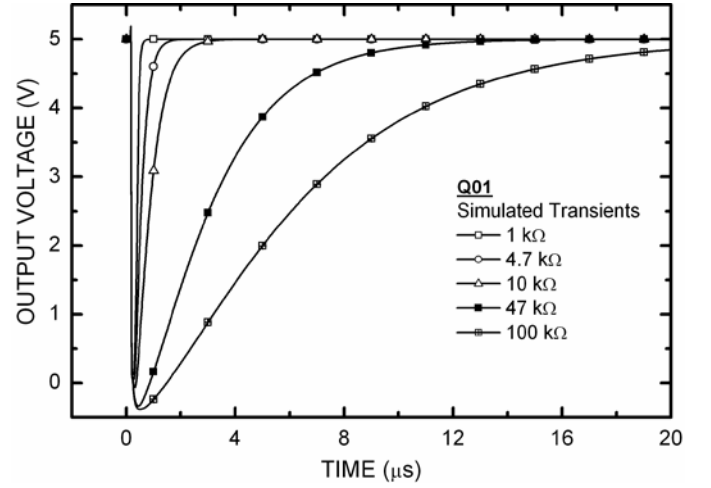


Fig. 8: Simulated negative-going transients measured in the LM311 voltage comparator.

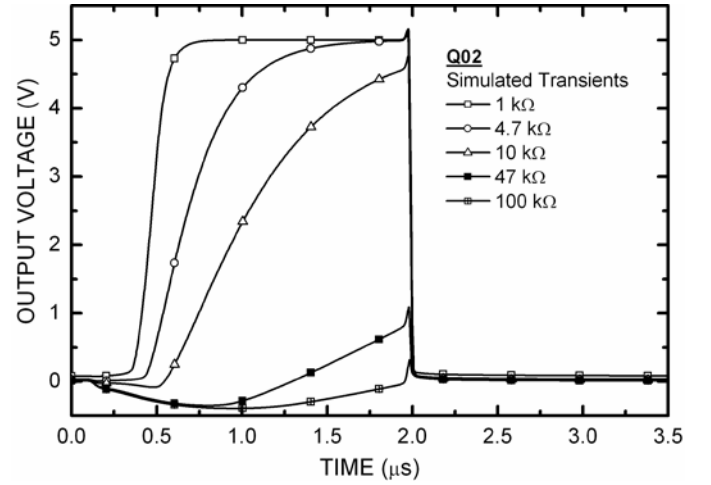


Fig. 9: Simulated positive-going transients measured in the LM311 voltage comparator.

#### IV. CONCLUSION

Single event transients that occur in analog devices are greatly affected by the resistor loading the output. Usually, they are mitigated by low values of the load resistor although in some situations this trend is not followed leading to harmful transients if the load resistor is not carefully chosen.

The results reported in this paper show how an incorrect selection of value of the resistor loading the output of some bipolar analog devices greatly changes the size, duration and shape of the single event transients.

Finally, the designers should bear in mind that, in the case of operational amplifiers, the feedback network also loads the device output so different pairs of resistor values even having the same ratio between them lead to different shapes of single event transients.

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